Deciphering variation in cotton yield, yield components and fiber quality

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ABSTRACT

Cotton yields have not increased in 10 years after rising much of the 20th century, posing risks to growers of this expensive to produce crop. Along with economic stresses on producers, yarn manufacturing has increasingly adopted rotor spinning to compete with synthetic fibers in the global economy, resulting in demand for less variable fiber properties to fully realize the high-output capabilities of rotor yarn manufacturing technology. We conducted studies to investigate effects of cultivar and plant density on variability in yield, within boll yield components, and fiber quality. Research has shown that boll occurrence is influenced by plant density, but effects on variability in yield components and fiber properties are not well characterized. We evaluated two cultivars, Deltapine 458BR and FiberMax 966, differing in yield components and fiber properties for yield, yield components, and variation for fiber properties when produced in 0.91 m spaced rows at plant densities 4, 9, 13, and 22 plants m^{-2}. Trials were conducted at Plains and Tifton, GA in 2001 and 2002. Plot size was six 36 m long rows. At maturity, plants from 6 m of one row of each plot were removed and bolls from these plants were hand picked and gathered by fruiting site for ginning, measurement of fiber properties by Advanced Fiber Information System (AFIS®), and determining yield components. The center two rows of each plot were machine harvested and ginned at the USDA Cotton Ginning Laboratory, Stoneville, MS. Fiber properties by AFIS were measured on the fiber from the plot yields in addition to fiber from fruiting sites. In 2001, we found a cultivar x plant density interaction for lint yield at Plains, with FiberMax 966 yielding similarly over plant densities, while Deltapine 458BR yields rose between four and nine plants m^{-2} and thereafter did not change. Deltapine 458BR responded to plant density through greater lint fraction as plant density increased. The yield stability of FiberMax 966 at Plains could reflect compensation in seed size and weight of fibers per seed. At Tifton, only cultivar and plant density main effects were significant at Tifton, with the highest yields produced at 22 plants m^{-2}. These findings suggest that high and stable yields might be accomplished by assembling yield components similar to those of FiberMax 966. Fiber length by weight percent coefficient of variation was affected by cultivar at Plains ($P<0.10$), while at Tifton a cultivar x plant density interaction ($P<0.05$) was found, where both cultivars produced the least variable length fiber at the lowest plant density. Short fiber content was affected by only cultivars ($P<0.05$) at Plains, while at Tifton the plant density main effect ($P<0.10$) revealed that the least short fiber content was produced at four plants m^{-2}. These findings suggest strategies to reduce variability in yield and fiber quality to benefit consumers and producers of fiber.

Introduction

Annual average world cotton yields increased most of the 20th century until about the last 15 years (Figure 1), while U.S. yields have not risen during the last 10 years combined with pronounced year to year yield volatility compared with similar time periods since national yields have been enumerated (Figure 2). This yield stagnation and volatility has prompted breeders to investigate alternate selection criteria to further enhance yield and yield stability.

Breeding cotton for high yield has resulted in more harvestable bolls per unit area and more lint relative to seed (Culp and Green, 1992), plus fruit set over time periods typically lasting a month or more (Jenkins *et al*., 1990). Additionally, many currently popular cultivars have small seed and are dependent on producing numerous seed per unit area upon which to bear lint to produce high yields (Coyle and Smith, 1997). Dependence of high yield on successful production of many seed per unit area predisposes many modern cultivars to low yield volatility when seed production is curtailed by poor growing conditions (Lewis, 2000).

Numerous studies have investigated effects of plant density as functions of between row distance and/or within-row spacing on cotton yield (Bednarz *et al*., 2000; Hawkins and Peacock, 1970; Hawkins and Peacock, 1973). In summary, as plant density increases either through closer within and/or between row spacing, the cotton plant produces fewer bolls per plant and the length of the fruiting period is condensed (Bednarz *et al*., 2000). Effects of plant density and fruiting site on expression of within boll yield components has not been studied and must be known before selection for these traits can be effectively practiced.

The objective of this research was to ascertain effects of cultivar, plant density, and fruiting position on expression of cotton yield components as a prerequisite to designing strategies for manipulating yield components through breeding to effect higher and more stable yields.

Experimental procedure

The cultivars Deltapine 458BR and FiberMax 966 were chosen to study their reaction in yield and yield components because they differ in seed size, average weight of fibers per seed, among other yield components. Plus, Deltapine 458BR is popular, being planted to 5.4% and 6% of 2001 and 2002 U.S. hectares, respectively (USDA-AMS, 2001; USDA-AMS, 2002) with its transgenic insect and weed pest management traits, while FiberMax 966 has high fiber strength among other desirable agronomic qualities, but small cottonseed market share (0.24% and 0.23% of 2001 and 2002 U.S. plantings, respectively). Trials were conducted in 2001 and 2002 at the University of Georgia Southwest Georgia Research Station, Plains, GA and the University of Georgia Ponder Research Farm near Tifton, GA. The soil type at Plains was a Greenville sandy clay loam, while at Tifton it was Tifton loamy sand. Plots consisted of six rows, with 0.91 m row spacing, 36 m long. Plots were over-seeded and then thinned by hand to achieve final plant stands of 4, 9, 13, and 22 plants m^{-2}. The treatment design was a factorial arrangement of cultivars and plant densities, while the experimental design was randomized complete block with four replicates at each location. Prior to machine harvest, plants from one 6 m section of either rows two or five of each six row plot were cut at ground level and bolls hand harvested by fruiting site (main-stem node and position for sympodial branches while cotton on monopodial branches was grouped by monopodial branch among all plants in the 6 m of row box mapped). Seed-cotton agglomerated from each fruiting site on sympodial branches and that grouped by monopodial branch from plants in the 6 m hand harvested section of row was ginned on a 10-saw Continental laboratory model gin and lint samples were submitted to the Cotton Incorporated Textile Services Laboratory for AFIS length and maturity analyses. The center two-rows of each plot were machine harvested and the seed-cotton was ginned at the USDA-ARS Cotton Ginning Laboratory, Stoneville, MS through the usual sequence of seed-cotton and lint cleaning appropriate for picker harvested cotton (Anthony, 1999). Gin turnout was calculated as the weight of the ginned lint divided by the initial seed-cotton weight after the seed-cotton samples from the trial were conditioned to constant moisture. Three lint sub-samples were taken from each plot during the ginning process upon which AFIS and HVI fiber properties were measured. As of this writing, the AFIS data from the plot yields has been analyzed. Because of the number of fruiting sites from box-mapping 6 m of plants per experimental unit, collection of the AFIS data by fruiting site and yield component data from the 2002 trial at Plains has yet to be completed. ANOVAs of all 2001 data were conducted by location because combined analyses across locations only results in 1 df for the F-test of cultivar differences in the mixed effects model.

Results and Discussion

We found a cultivar x plant density interaction ($P<0.05$) for gin turnout at Plains, but not at Tifton ($P>0.10$). At Plains, gin turnout of Deltapine 458BR was highest at 22 plants m^{-2} (38.1%), while gin turnout of FiberMax 966 was highest at four plants m^{-2} (39.7%), with cultivars responding in opposite direction as plant density varied (data not shown). At Tifton, only cultivar differences ($P<0.01$) in gin turnout were found (Deltapine 458BR=37.7%; FiberMax 966=39.2%).

For lint yield, we found a cultivar x plant density interaction ($P<0.05$) at Plains, characterized by Deltapine 458BR yielding more at 9, 13, and 22 plants m^{-2} compared with 4 plants m^{-2} while yield of FiberMax 966 was stable over plant densities (Table 1). At Tifton, main effects of cultivar and plant density were significant ($P<0.01$), with yield increasing between four and nine plants m^{-2} averaged over both cultivars.

We found cultivar x plant density x main stem node interactions for the within boll yield components lint fraction, seed size, and weight of fibers per seed determined from 1st fruiting positions on sympodial branches in all trials except Tifton in 2001 (Table 2). Lint fraction of FiberMax 966 was least responsive to plant density, while lint fraction of Deltapine 458BR generally rose as plant density increased at Plains (Table 3) and Tifton (data not shown). With respect to effects of plant density on a sampling regime to evaluate lint fraction, determining lint fraction from 1st position bolls in the mid-portion of plants (ca. nodes 10-13) would maintain the rank between Deltapine 458BR with lesser lint fraction and FiberMax 966 with greater lint fraction (Table 3). The same conclusion was drawn from results of the Tifton experiment (data not shown). For seed size (Table 4) and average weight of fibers per seed (Table 5), we reached the same conclusion concerning rank between Deltapine 458BR and FiberMax 966 that express extremes for these traits. These findings suggest that within the plant densities most likely to be employed in selection experiments (4 to 13 plants m^{-2}), that stand variation within this range would not confound separation of genetic differences in these within boll yield components.

Another issue addressed in this study was the effects of plant density on variation in fiber properties. This hypothesis derives from the fact that plant density affects where fruit are set on the cotton plant and thus the environmental and nutritional conditions under which these fruit develop. The foundational data to answer this question lies in the length and maturity distributions determined from fiber derived through the box plant mapping experiments. These data are still being collected, but we do have AFIS measurements on fiber from the plot yields. Fiber from the plot yields was generated by ginning through the USDA-ARS Cotton Ginning Lab, and thus substantially mimics fiber from commercial gins. The AFIS fiber length by weight percent coefficient of variation revealed effects of cultivar at Plains (P<0.10) and a cultivar x plant density interaction (P<0.05) at Tifton. Interestingly, both cultivars produced the least variable length fiber at four plants m^{-2} (Table 6). Cultivars (P<0.05) differed for short fiber content by weight at Plains, while at Tifton the main effect of plant density (P<0.10) revealed that the least short fiber content was produced at the lowest plant density. We hypothesize that the more uniform length fiber based on lowest fiber length by weight percent coefficient of variation and least short fiber content by weight at the lowest plant density reflects enhanced fruit nutrition from lack of competition for sunlight, soil nutrients, and water from neighboring plants compared with more dense stands.

Conclusions

These data from cultivars representing extremes of seed size and weight of fibers per seed suggest it is not necessary to rigorously control plant density within the range of four to 22 plants m^{-2} when evaluating progeny for within boll yield components.

The finding that a cultivar with the combination of yield components as in FiberMax 966 resulting in stable yields across plant densities suggests assembling yield components similar to those of FiberMax 966 in breeding for higher and more stable yields.

Deltapine 458BR and FiberMax 966 both produced the least variable length fiber at four plants m^{-2}, suggesting scaled up studies producing bale-sized quantities of cotton to verify through yarn properties whether the less variable fiber is of value in processing.

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Table 1. *Lint yields (kg ha[-1]) from cultivar x plant density experiment conducted at Plains and Tifton, GA in 2001.*

Location	Effect	Plant density			
		4	9	13	22
Plains	DP 458BR	1202	1381	1421	1440
	FiberMax 966	1333	1316	1364	1322
Cultivar x Density (P=0.0136)		LSD0.05=108			
		DP 458BR	FiberMax 966		
Tifton	Cultivar P=0.0002	1444	1544		
		Plant density			
		4	9	13	22
Plant density (P=0.0001)		1331	1516	1538	1592
		LSD0.05=66			

Table 2. *Results of the ANOVA of lint fraction and certain within boll yield component traits from 1st fruiting position bolls in cultivar x plant density x main stem node studies conducted in 2001 at Plains and Tifton, GA USA.*

Source of variation	Yield components					
	Lint fraction		Seed size		Weight fibers sSeed[-1]	
	Plains	Tifton	Plains	Tifton	Plains	Tifton
	Pr > F					
Cultivar	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Density	0.0440	0.0034	0.0149	0.0001	0.0780	0.4600
Cultivar x Density	0.1510	0.4821	0.0449	0.3895	0.0857	0.5488
Node	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Cultivar x Node	0.0351	0.2977	0.6124	0.0209	0.5459	0.0029
Density x Node	0.0001	0.0352	0.4671	0.1194	0.0179	0.5443
Cultivar x Density x Node	0.0737	0.0102	0.0082	0.0915	0.0357	0.4021

Table 3. *Lint fraction (%) by main stem node from 1st fruiting positions determined in cultivar x plant density experiment conducted at Plains, GA in 2001.*

Harvesting method	Parameter value		
	Lint turnout %	Weight of 100 seeds (g)	Market classification
Picker	32.4	97.1	Strict Low Middling
Stripper Shaker	29.5	87.9	Low Middling
LSD (p=0,05)	1.3	3.6	

Table 4. *Seed size (mg/seed) by main stem node from 1st fruiting positions determined in cultivar x plant density experiment conducted at Plains, GA in 2001.*

	DP458BR				FiberMax966			
	Plant Density m^{-2}				Plant Density m^{-2}			
Node	4	9	13	22	4	9	13	22
5	53.9	77.4	65.5	66.5	104.4	62.3	96.8	89.2
6	70.0	73.0	67.8	70.2	99.6	74.5	96.7	93.1
7	79.9	75.7	72.5	71.4	78.5	101.4	84.0	99.4
8	77.5	76.2	73.5	76.0	108.3	104.8	100.0	99.3
9	70.0	77.4	73.3	75.5	101.5	99.7	100.5	96.9
10	75.9	76.6	76.3	76.8	107.9	101.1	99.0	98.6
11	79.0	78.3	76.2	76.5	103.9	100.0	97.0	97.4
12	80.5	77.0	75.3	75.2	101.7	98.1	96.8	94.8
13	77.8	76.1	73.8	86.6	102.8	98.3	95.9	95.1
14	76.1	74.0	71.6	71.1	98.1	94.5	93.7	91.5
15	74.7	71.3	69.1	68.0	95.8	94.5	92.2	87.6
16	71.6	70.6	66.4	63.8	95.8	92.2	89.0	82.1
17	71.8	69.5	66.5	65.2	94.0	89.7	85.8	85.0
18	67.8	65.9	50.8	63.5	92.2	84.2	82.5	88.0
LSD (P = 0.05) = 12.2 mg/seed								

Table 5. *Average weight fibers per seed (mg fiber/seed) by main stem node from 1st fruiting positions determined in cultivar x plant density experiment conducted at Plains, GA in 2001.*

	DP458BR				FiberMax966			
	Plant Density m^{-2}				Plant Density m^{-2}			
Node	4	9	13	22	4	9	13	22
5	34.5	53.3	42.1	42.6	67.7	47.1	63.9	58.1
6	43.7	51.6	49.4	47.5	69.5	48.9	69.0	64.0
7	55.6	51.6	51.5	51.9	67.6	73.2	59.3	72.4
8	54.6	55.4	53.3	59.0	76.1	76.2	72.3	73.5
9	60.0	58.9	53.6	60.6	75.1	75.5	76.3	76.1
10	55.4	58.2	58.0	64.0	84.1	82.0	78.7	78.8
11	58.5	62.5	61.0	65.1	83.0	83.7	81.9	83.4
12	59.0	62.8	62.4	66.3	84.6	84.6	85.6	84.9
13	61.3	64.4	62.3	76.5	86.9	87.2	85.6	83.9
14	61.5	64.0	62.0	62.8	88.7	86.7	83.4	79.1
15	63.0	60.6	60.3	58.2	84.4	84.4	80.6	75.1
16	61.6	59.7	56.7	54.4	85.7	81.5	76.0	65.3
17	63.3	58.4	54.7	52.8	79.8	77.3	73.8	72.7
18	65.7	51.7	42.6	45.9	79.2	74.5	68.6	75.0
LSD (P = 0.05) 10.1 mg fiber/seed								

Table 6. Fiber length measurements by AFIS on fiber from plot yields ginned through USDA-ARS Cotton Gin Lab from cultivar x plant density experiments conducted at Plains and Tifton, GA in 2001.

Location	Effect	Fiber length by weight coefficient of variation (%CV) by AFIS			
		DP 458BR		FiberMax 966	
Plains	Cultivar (P=0.0505)	32.4		32.8	
		Plant Density			
Tifton	Cultivar x Density (P=0.0495)	4	9	13	22
	DP 458BR	33.4	34.0	33.3	34.5
	FiberMax 966	34.1	34.8	35.4	35.2
	LSD (P=0.05)	0.6			
		Short fiber content by weight (%) from AFIS			
		DP 458BR		FiberMax 966	
Plains	Cultivar (P=0.0030)	7.5		7.0	
		Plant Density			
Tifton	Plant Density P=0.0609	4	9	13	22
		8.8	9.4	9.4	9.5
	LSD (P=0.05)	0.6			

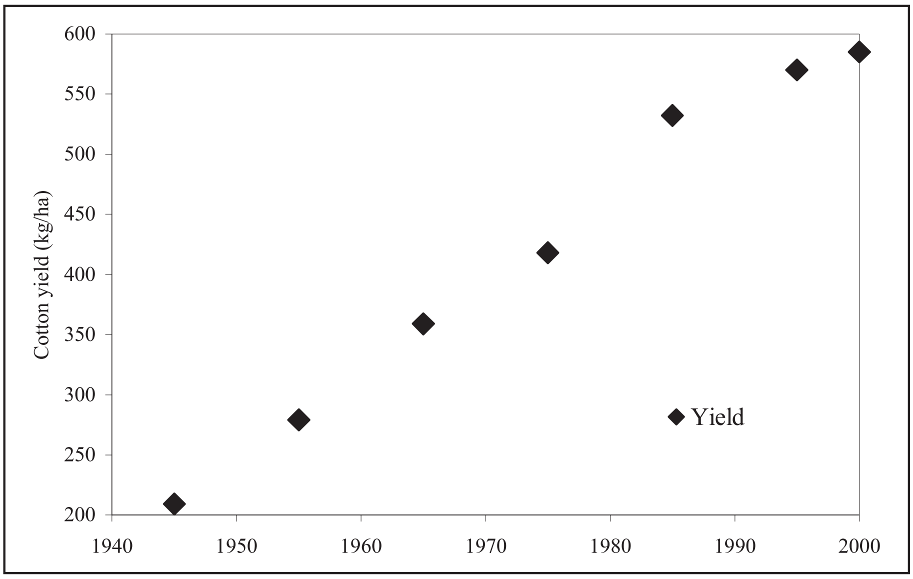

Figure 1. *World average per hectare cotton yields since 1940, depicting steady increases until recent years (ICAC, 2002).*

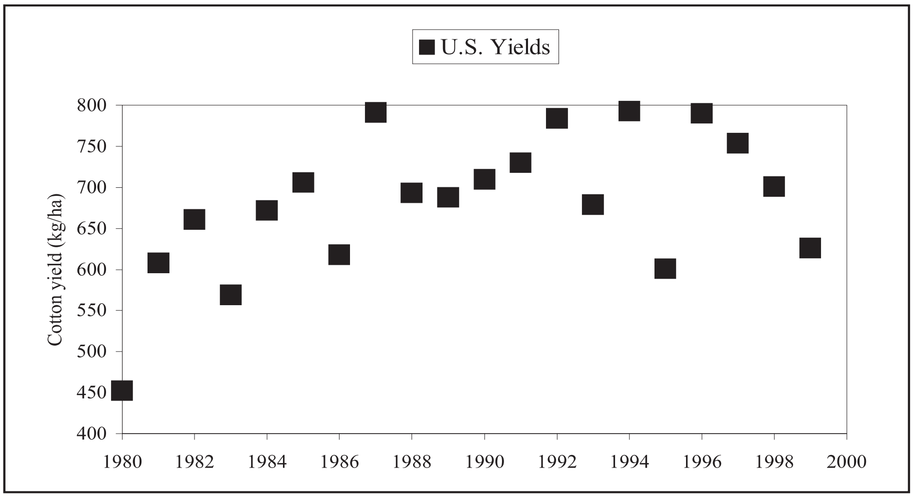

Figure 2. *Average per hectare U.S. cotton yields last 20 years (National Cotton Council, 2001).*